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(54) **AUTOMATING WORKFLOW VALIDATION**

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G06F 11/07 (2006.01)

(52) **U.S. Cl.**
CPC ***G06F 9/44*** (2013.01); ***G06F 11/0751*** (2013.01); ***G06Q 10/0633*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,937,388 A 8/1999 Davis et al.
5,987,422 A * 11/1999 Buzsaki 705/7.13
6,182,245 B1 * 1/2001 Akin et al. 714/38.14
2003/0018508 A1 1/2003 Schwanke
2004/0019512 A1 1/2004 Nonaka
2004/0254768 A1 12/2004 Kim et al.
2006/0179422 A1 * 8/2006 Gortler 717/124
2006/0195347 A1 8/2006 Bultmeyer et al.
2008/0243902 A1 10/2008 Rong et al.
2009/0281865 A1 11/2009 Stoitsev
2011/0055673 A1 3/2011 Teng et al.
2011/0113287 A1 * 5/2011 Gururaj 714/37
2013/0219226 A1 * 8/2013 Hachmeister et al. 714/38.1

* cited by examiner

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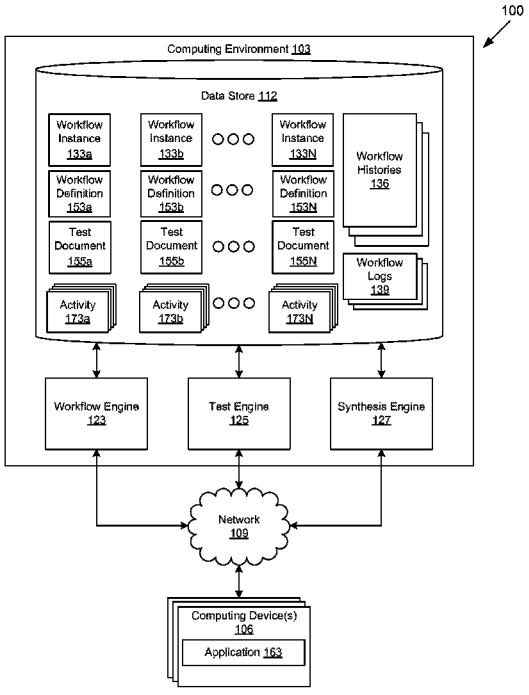
(57) **ABSTRACT**

A test document associated with a workflow definition is obtained, the test document including an input for an action of the workflow definition and an expected state for the workflow definition based on the input. The input is delivered for the action of a workflow instance, the workflow instance being an instance of the workflow definition executed by a workflow engine, and the action determined based upon a present state of the workflow instance. A next state of the workflow instance is obtained, where the next state is determined by the workflow engine based upon the present state, the action and the input. The next state of the workflow instance is compared to the expected state of the test document.

24 Claims, 5 Drawing Sheets



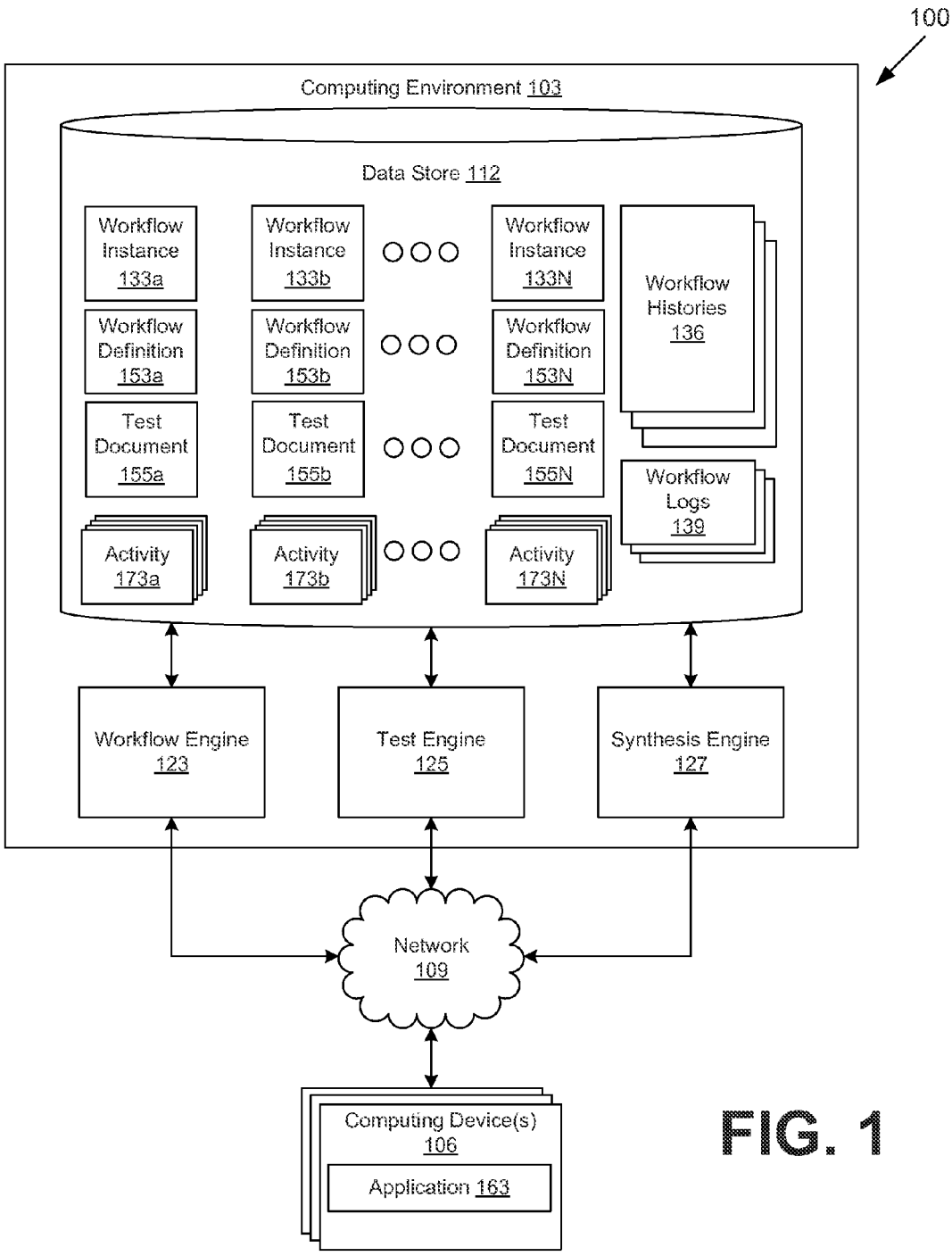

100
Computing Environment 103
Data Store 112
Workflow Instance 133a
Workflow Instance 133b
Workflow Instance 133N
Workflow Histories 136
Workflow Definition 153a
Workflow Definition 153b
Workflow Definition 153N
Test Document 155a
Test Document 155b
Test Document 155N
Workflow Logs 139
Activity 173a
Activity 173b
Activity 173N
Workflow Engine 123
Test Engine 125
Synthesis Engine 127
Network 109
Computing Device(s) 106
Application 163

FIG. 1

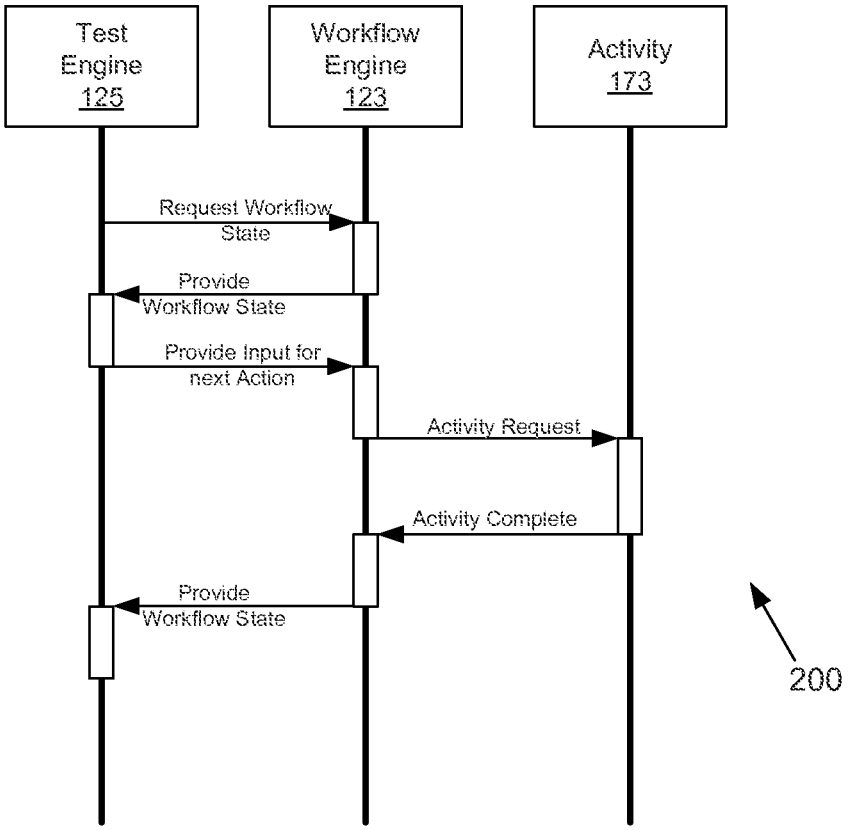

Test Engine 125
Workflow Engine 123
Activity 173
Request Workflow State
Provide Workflow State
Provide Input for next Action
Activity Request
Activity Complete
Provide Workflow State
200

FIG. 2

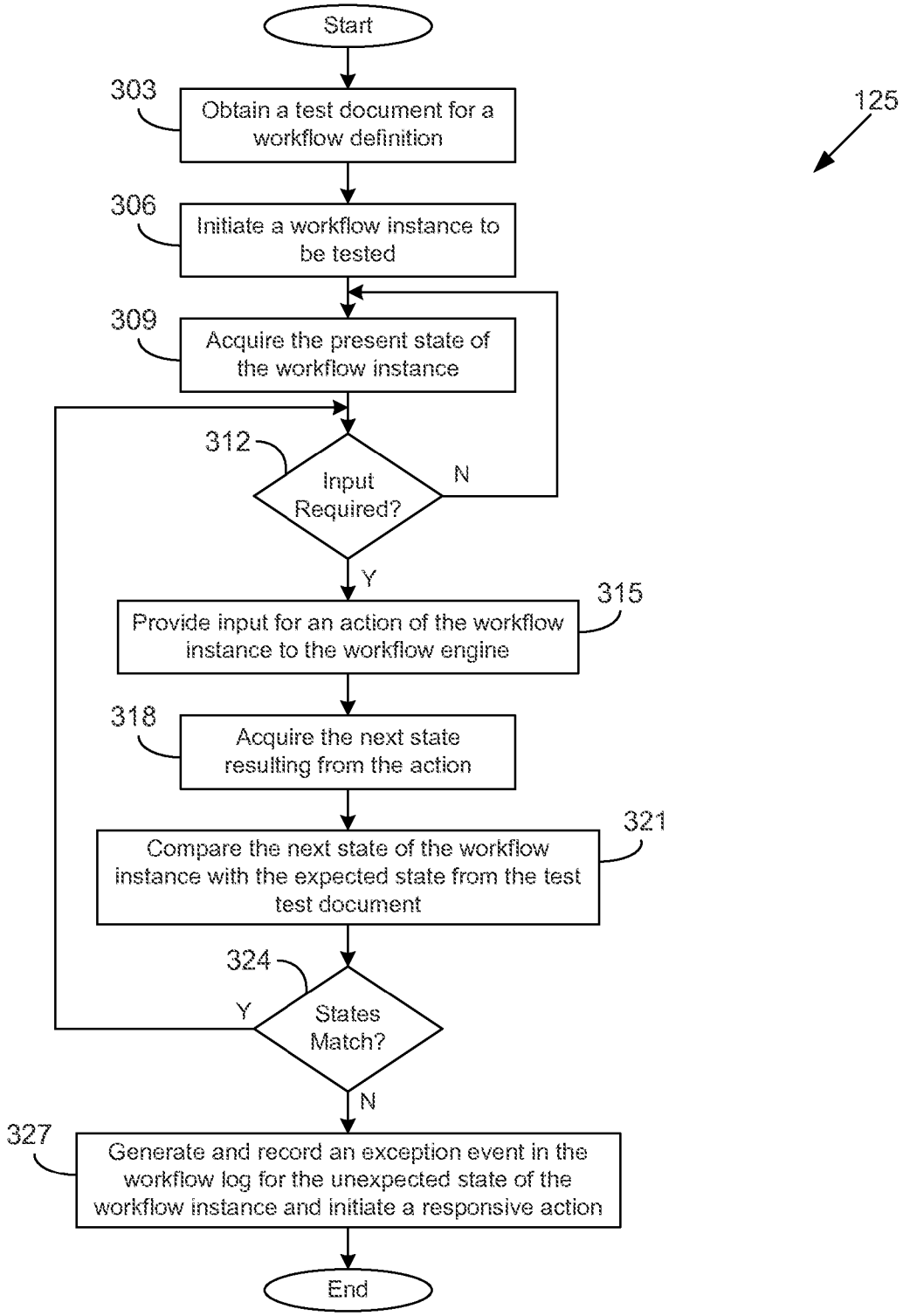

Start
303
Obtain a test document for a workflow definition
306
Initiate a workflow instance to be tested
309
Acquire the present state of the workflow instance
312
Input Required?
N
Y
315
Provide input for an action of the workflow instance to the workflow engine
318
Acquire the next state resulting from the action
321
Compare the next state of the workflow instance with the expected state from the test test document
324
States Match?
Y
N
327
Generate and record an exception event in the workflow log for the unexpected state of the workflow instance and initiate a responsive action
End
125

FIG. 3

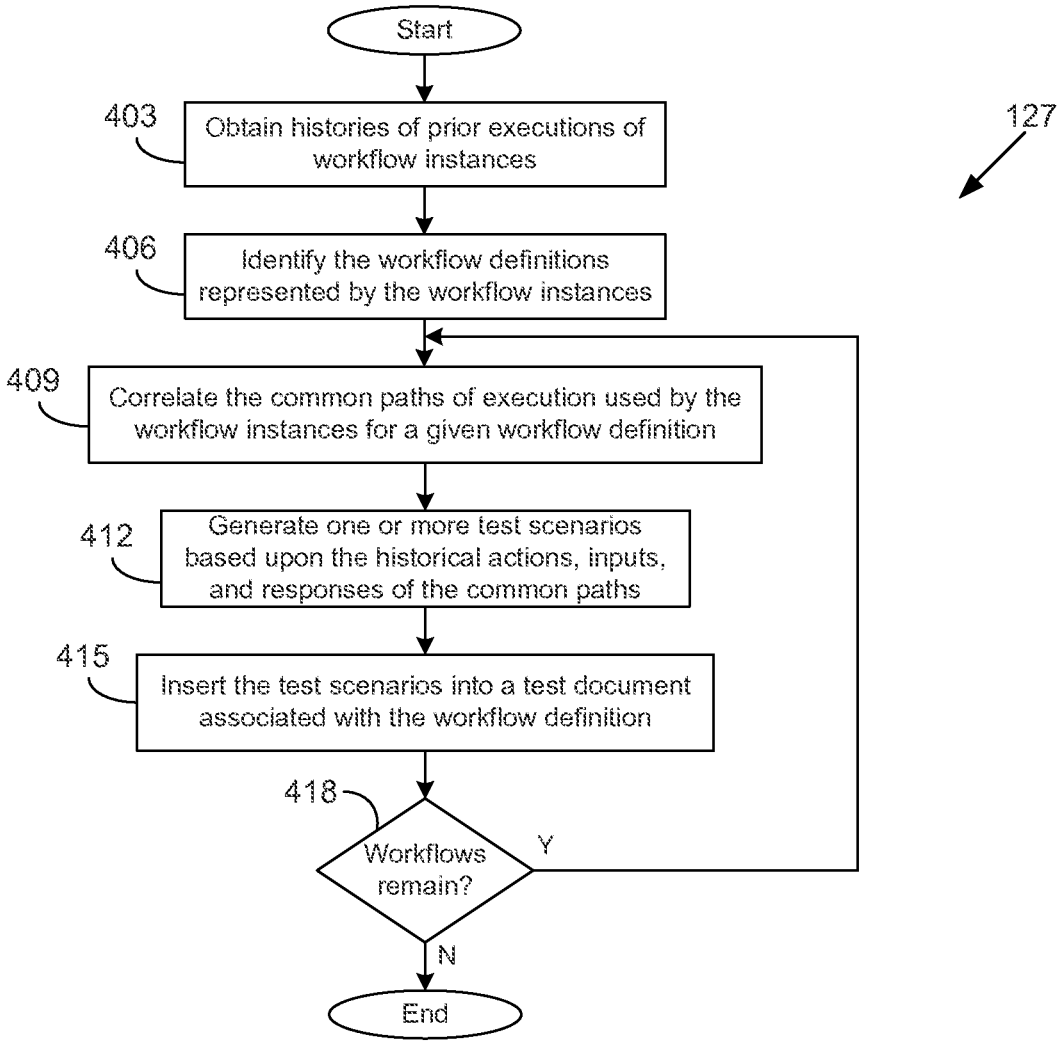

Start
403
Obtain histories of prior executions of workflow instances
406
Identify the workflow definitions represented by the workflow instances
409
Correlate the common paths of execution used by the workflow instances for a given workflow definition
412
Generate one or more test scenarios based upon the historical actions, inputs, and responses of the common paths
415
Insert the test scenarios into a test document associated with the workflow definition
418
Workflows remain?
Y
N
End
127

FIG. 4

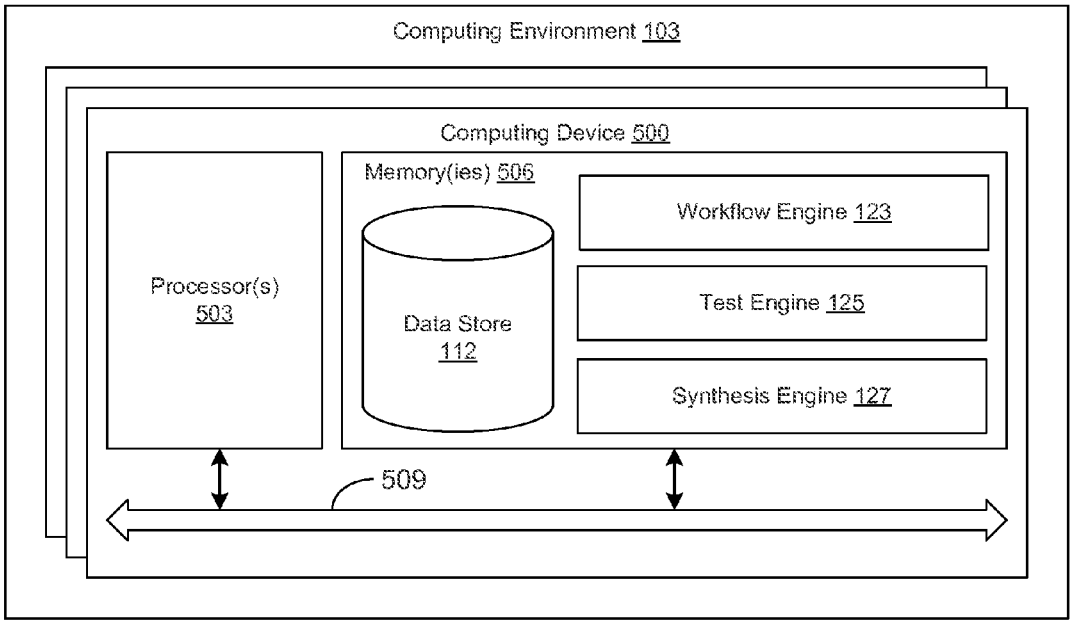

Computing Environment 103
Computing Device 500
Memory(ies) 506
Workflow Engine 123
Processor(s) 503
Data Store 112
Test Engine 125
Synthesis Engine 127
509

FIG. 5

AUTOMATING WORKFLOW VALIDATION

BACKGROUND

Workflow management systems typically model a business process by defining a workflow comprising a set of tasks to produce a result. Complex business processes may necessitate complex workflows. It can be difficult to validate workflows with current technologies that do not offer the flexibility needed to handle significant complexity.

BRIEF DESCRIPTION OF THE DRAWINGS

Many aspects of the present disclosure can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the disclosure. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views.

FIG. **1** is a drawing of a networked environment according to various embodiments of the present disclosure.

FIG. **2** is a drawing of a communication diagram that illustrates one example of communication between various components in a computing environment in the networked environment of FIG. **1** according to an embodiment of the present disclosure.

FIG. **3** is a flowchart illustrating one example of functionality implemented as portions of a test engine executed in the computing environment in the networked environment of FIG. **1** according to various embodiments of the present disclosure.

FIG. **4** is a flowchart illustrating one example of functionality implemented as portions of a synthesis engine executed in the computing environment in the networked environment of FIG. **1** according to various embodiments of the present disclosure.

FIG. **5** is a schematic block diagram that provides one example illustration of the computing environment employed in the networked environment of FIG. **1** according to various embodiments of the present disclosure.

DETAILED DESCRIPTION

Disclosed are various embodiments facilitating validation of the operation of one or more actions of a workflow. A workflow definition may contain many possible paths through the various possible actions of a workflow. In order to verify that the workflow definition operates as expected, a test document may be created that specifies input for one or more of actions of the workflow definition, as well as a corresponding expected state resulting from each of the specified actions. In some embodiments, portions of the test document may be created by a synthesis engine based upon the history from prior instances of the workflow definition.

To begin the validation, a test engine may obtain the test document specifying input to one or more actions of a workflow instance associated with the workflow definition. The test engine may provide the input to a workflow engine executing the workflow instance, then validate that the post-action state of the workflow instance matches the expected state specified in the test document. The expected state may be used to ensure that the workflow instance takes the proper path through the actions of the workflow definition, and that the history for the workflow instance is updated correctly. In the following discussion, a general description of the system and its components is provided, followed by a discussion of the operation of the same.

With reference to FIG. **1**, shown is a networked environment **100** according to various embodiments. The networked environment **100** includes a computing environment **103** in data communication with one or more computing devices **106** by way of a network **109**. The network **109** includes, for example, the Internet, intranets, extranets, wide area networks (WANs), local area networks (LANs), wired networks, wireless networks, or other suitable networks, etc., or any combination of two or more such networks.

The computing environment **103** may comprise, for example, a server computer or any other system providing computing capability. Alternatively, the computing environment **103** may comprise a plurality of servers or other computing devices that are arranged, for example, in one or more server banks or computer banks or other arrangements. For example, the computing environment **103** may comprise a cluster computing resource, a grid computing resource, and/or any other distributed computing arrangement. The computing environment **103** may be located in a single installation or may be distributed among many different geographical locations.

Various applications and/or other functionality may be executed in the computing environment **103** according to various embodiments. Also, various data is stored in a data store **112** that is accessible to the computing environment **103**. The data store **112** may be representative of a plurality of data stores **112** as can be appreciated. The data stored in the data store **112**, for example, is associated with the operation of the various applications and/or functional entities described below.

The components executed on the computing environment **103**, for example, include a workflow engine **123**, a test engine **125**, a synthesis engine **127**, and other applications, services, processes, systems, engines, or functionality not discussed in detail herein. The workflow engine **123** is executed to orchestrate and execute instances of workflows ("workflow instances") as will be described. The workflow engine **123** is a generic workflow processor that may embody a functional expression of a given workflow definition. Accordingly, the workflow engine **123** is a stateless entity that processes the workflow instances according to the respective workflow definition and workflow history. In this respect, the workflow engine **123** is configured to identify the activities, actions, or steps to be performed for a specific workflow instance based upon the respective workflow definition as will be described. In one embodiment, the workflow engine **123** comprises a class that may be instantiated multiple times. Thus, there may be many instances of various workflow engines **123** executed by the computing environment **103** at any given time.

The test engine **125** is executed to facilitate automated testing of workflow instances according to a pre-defined test document. The test engine **125** may communicate with the workflow engine **123** and/or other services using various protocols such as, for example, simple object access protocol (SOAP), representational state transfer (REST), remote procedure call (RPC), and/or other protocols for inter-process communication. The synthesis engine **127** is executed to generate testing scenarios used within the test documents based upon prior executions of workflow instances. In order to produce the testing scenarios, the synthesis engine **127** may examine the workflow logs produced by the workflow engine **123** during the execution of the various workflow instances.

The data stored in the data store **112** includes, for example, several workflow instances **133***a*-N, workflow histories **136**, workflow logs **139**, several workflow definitions **153***a*-N, several test documents **155***a*-N, several activities **173***a*-N, and potentially other data. Each workflow instance **133** is an instance of a given workflow definition **153** and may be represented by the data making up the workflow instance **133** in its entirety, or a workflow instance **133** may be represented by virtue of an identifier that is associated with data embodying a workflow instance **133** stored elsewhere. The workflow represented by each workflow instance **133** is orchestrated by the workflow engine **123**.

Each workflow history **136** is associated with a respective one of the workflow instances **133** processed by the workflow engine **123**. The workflow histories **136** each comprise, for example, a list of events that have occurred during the execution of a given workflow instance **133** over time. To this end, the events listed in a given workflow history **136** act as a record of the execution of a workflow instance **133**. Such events may be expressed using, for example, extensible markup language (XML), JavaScript object notation (JSON), or other such languages. Individual workflow logs **139** include various data related to corresponding workflow instances **133***a*-N executed previously by the workflow engine **123**. The workflow logs **139** may include the workflow history **136** for a given workflow instance **133**, identifiers for the workflow instance **133** and the associated workflow definition **153**, data used as input for various states of the workflow instance **133**, exceptions or errors reported during execution of the workflow instance **133**, and/or other data associated with a previous execution of one or more workflow instances **133***a*-N.

Each workflow definition **153** defines the activities, actions, and/or steps (collectively referred to as the "actions") to be carried out for each associated workflow instance **133**. In some embodiments, the actions of a workflow definition **153** may comprise one or more subordinate tasks ("sub-tasks"). In some embodiments, the workflow instance may not progress to the next action until each of the sub-tasks is complete. In other embodiments, the workflow instance **133** may progress to the next action concurrently with the execution of the sub-tasks. The workflow definition **153** may be expressed using, for example, XML process definition language (XPDL), business process execution language (BPEL), or other workflow process definition languages.

Each test document **155** corresponds to a workflow definition **153** and provides an input for one or more states of a workflow instance **133** under test and a corresponding expected resulting state for the workflow instance **133**. In some embodiments, a test document **155** may be represented as an extensible markup language (XML) document or a JavaScript Object Notation (JSON) document. The test document **155** may provide an input for a subset of the possible states along one or more possible paths of execution of the workflow definition **153**. In some embodiments, the test document **155** may provide inputs for one or more sub-tasks of an action within the workflow definition **153**. In other embodiments, the test document **155** may specify a responsive action to initiate in the event that the expected resulting state of the workflow instance **133** under test does not match the actual resulting state of the workflow instance. As a non-limiting example, the responsive action may comprise logging the event, generating an alarm, repeating the action that resulted in the unexpected state, restarting the workflow instance **133** under test, and/or other possible responsive actions.

Each of the activities **173** may be executed by the computing environment **103** to perform or facilitate performance of one or more actions, tasks, or functions that comprise at least a portion of a given workflow instance **133** based upon a request from the workflow engine **123** as will be described. The activities **173** may facilitate performance of one or more actions, tasks, or functions of a given workflow instance **133** by, for example, initiating execution of one or more applications, providing notice to assignees of tasks, monitoring performance of the tasks, and/or other methods of facilitation as can be appreciated. In some embodiments, the actions, tasks, or functions facilitated by the activities **173** may be performed asynchronously. In other embodiments, the applications initiated by the activities **173** may be performed in computing devices remote to the computing environment **103**. The activities **173** may comprise a class that is instantiated multiple times to handle the workflow processing load from the workflow engine **123** as will be described.

The computing device or devices **106** may comprise, for example, a server computer or any other system providing computing capability. Alternatively, the computing device **106** may comprise a plurality of servers or other computing devices that are arranged, for example, in one or more server banks or computer banks or other arrangements. For example, the computing device **106** may comprise a cluster computing resource, a grid computing resource, and/or any other distributed computing arrangement. The computing device **106** may be located in a single installation or may be distributed among many different geographical locations.

The components executed on the computing device or devices **106**, for example, include an application **163** and other applications, services, processes, systems, engines, or functionality not discussed in detail herein. The application **163** is executed to perform one or more actions of a given workflow instance **133**. The application **163** may obtain input for the actions to be performed for a workflow instance **133** and may return the result of the action based upon the input. As a non-limiting example, the application **163** may perform the action of initiating shipment of the items from a paid order. The application **163** may obtain an order number as input, then provide a shipment confirmation number as a result of the action performed.

The networked environment **100** is configured to execute workflow instances **133** that perform various functions. One example of such a workflow that may be embodied in workflow instances **133** might be a process to implement the payment for a purchase of an item online over the Internet. Such a process may involve various actions or tasks such as inputting a payment instrument such as a credit card number or other instrument, performing a fraud check on the payment instrument, and sending a shipment request to a fulfillment center to implement the fulfillment of the order. There may be many other actions or tasks involved in such a process, where the above actions or tasks are described merely for the purposes of illustration.

To this end, a workflow may involve various components, persons, applications, and other entities that are involved in the processing of data to complete a workflow instance **133**. In the case of the processing of payment for an order, for example, such an order may be processed through various departments and other entities for ultimate authorization and purchase. A given workflow instance **133** may involve human intervention at some point, or may be entirely automated. The human intervention may involve interaction with a given activity **173** on the part of an individual as can be appreciated.

Next, a general discussion of the networked environment **100** is described with respect to the execution of various

workflow instances **133** according to various embodiments. To begin, an operator or an application external to the networked environment **100** may interact with a test engine **125** to initiate testing of a particular workflow definition **153**. To this end, a test document **155** associated with the workflow definition **153** may be obtained by the test engine **125**. In response, the test engine **125** may create or initiate creation of a workflow instance **133** associated with the workflow definition **153** under test. The workflow engine **123** ultimately orchestrates the execution of the workflow instance **133**, while the direction and input necessary for the execution of the workflow instance **133** is provided by the test engine **125** based upon the test document **155**.

To this end, the workflow engine **123** retrieves any workflow history **136** and workflow definition **153** from the data store **112** for such workflow instance **133**. In some embodiments, an initial state for the workflow instance **133** may be specified by the test document **155**. The workflow engine **123** also obtains the data associated with the respective workflow instance **133** from the data store **112** and/or other location. Once the respective workflow history **136**, workflow definition **153**, and other information embodying the workflow instance **133** are obtained, then the workflow engine **123** may begin processing the workflow instance **133**. The test engine **125** may establish a communications interface with the workflow engine **123** such that the test engine **125** obtains the state of the workflow instance **133**, as well as provides input required for one or more of the various actions of the workflow instance **133**.

Once the workflow history **136** and other information embodying the workflow instance **133** are received by the respective workflow engine **123**, then the workflow engine **123** processes the workflow definition **153** and examines the workflow history **136** in order to determine a next action to be taken for the respective workflow instance **133**. To this end, the generic workflow engine **123** becomes a functional embodiment of the workflow definition **153** that is configured to review the workflow history **136** and identify a next action to be taken for the workflow instance **133**.

The workflow engine **123** may determine that the next action of the workflow instance **133** requires input that would typically be provided by a user or an application executing on a computing device. Upon obtaining the state of the workflow instance **133**, the test engine **125** may determine if the test document **155** specifies an input for the next action. If such an input is provided in the test document **155**, the test engine **125** may communicate the input to the workflow engine **123**. Alternatively, if the test document **155** does not specify an input for a given action, the test engine **125** may obtain the input from a user through a user-interface and/or from another input source as can be appreciated.

As a non-limiting example, an action of a workflow definition **153** may be to obtain an order number of an order to be processed for shipping. During ordinary operation of the workflow instances **133**, the workflow engine **123** may obtain this order number from a user, from the data store **112**, or through another operation specified in the workflow definition **153**. However, if the test document **155** associated with the workflow definition **153** under test specifies an input for the particular action, the test engine **125** may bypass the input procedure defined for the action. In the present example, the test engine **125** may cause the workflow engine **123** executing the workflow instance **133** to bypass the input source for the action and instead provide the order number (i.e., the input) specified in the test document **155**.

In some embodiments, the test document **155** may contain references, scripts, network links, and/or other dynamic, "run-time" sources for providing input. Furthermore, a test document **155** may contain a mixture of static and dynamic input sources. Returning to the previous example, the test document **155** may specify one or more order numbers, as well as, for example, a uniform resource identifier (URI) providing a link to another source of order numbers.

In other embodiments, the action of a workflow definition **153** may comprise one or more sub-tasks, which may themselves continue to be further subdivided. As with the singular actions, the test document **155** associated with the workflow definition **153** may specify input data associated with one or more of the sub-tasks and/or other lineal tasks of an action. As a non-limiting example, an action of a workflow definition **153** may be to obtain payment for an order. The action may be divided into sub-tasks such as obtaining a payment method from a user, submitting a request for payment using the payment method, and providing confirmation of the payment processing to the user.

Upon obtaining the input for the action of the workflow instance **133**, the workflow engine **123** schedules an activity **173** that performs or facilitates performance of the next action and any sub-tasks to be executed with respect to the workflow instance **133**. To this end, this may involve placing the workflow instance **133** in a queue associated with a respective activity **173** to be performed.

Once the activity **173** indicates the next action has been completed, the activity **173** sends a message to the workflow engine **123** that such processing is complete. Thereafter, the test engine **125** may compare the data associated with the state of the workflow instance **133** after completing the activity **173** with the expected state of the workflow instance specified by the test document **155**. Such a testing scenario may permit testing of not only the operation of the workflow instance **133**, but potentially the operation of one or more applications **163** carrying out the action. For example, an action of a workflow definition **153** may be to obtain payment for an order. The action may be divided into sub-tasks such as obtaining a payment method from a user, submitting a request for payment using the payment method, and providing a payment confirmation number to the user. In this example, submitting a request for payment may comprise the application **163** obtaining authorization for payment.

If the payment method specified in the test document **155** is an identifier for an expired gift certificate, the expected state of the workflow instance **133** may be an error state with no defined payment confirmation number provided by the application **163**. If the state of the workflow instance **133**, including the data returned by the application **163**, matches the expected state of the test document **155**, the test engine **125** may record the results of the test of this action in the workflow log **139**, and the workflow instance **133** may proceed to the next action. Alternatively, if the states do not match, the test engine **125** may record the event as a state mismatch. Additionally, based upon the state mismatch, the test engine **125** may terminate the execution of the particular workflow instance **133**, attempt to repeat the action, restart the workflow instance **133** from the beginning, and/or other possible responses. In some embodiments, the response to a state mismatch for a given expected state may be specified by the test document **155**.

It should be noted that a workflow instance **133** created for testing purposes may or may not be executed to completion, even if the workflow instance **133** does not deviate from expected states of the test document **155**. For various possible reasons, the workflow engine **123** or the test engine **125** may determine that the execution of the particular workflow instance **133** should end. Such a "terminal" action may com-

prise an action or task inherent in the workflow of the workflow instance **133**, or such action may comprise closing the workflow instance **133** due to the fact that the workflow is complete. If the workflow is complete, then the workflow engine **123** closes the workflow instance **133** by performing any needed closing tasks without applying the workflow instance **133** to an activity **173** as can be appreciated. Alternatively, an activity **173** may be employed that performs the closing tasks.

In addition to the foregoing, the workflow engine **123** also records events in the respective workflow histories **136** of the workflow instances **133** that it handles. As non-limiting examples, such events may comprise receiving input for a workflow instance **133** and the source of the input, the workflow engine **123** determining a next action for the workflow instance **133** and the basis for determining the action, initiating an activity **173** for the workflow instance **133**, receiving a workflow instance **133** from an activity **173** after completion, an indication that a workflow instance **133** has completed or otherwise terminated, and/or other events. In addition, events may record various failure conditions such as the failure of a workflow engine **123** to timely determine the next action to be performed, the failure of an activity **173** to perform one or more tasks with respect to the workflow for a workflow instance **133**, and/or other possible failure states.

In some embodiments, the synthesis engine **127** may correlate the workflow histories **136** of prior executions of various workflow instances **133***a*-N in order to produce and/or extend the testing scenarios of the test documents **155***a*-N. To this end, the synthesis engine **127** may identify the prior executions of workflow instances **133** sharing the same workflow definition **153**. The workflow instances **133** may be correlated to identify common paths of execution taken from among the various potential paths of execution provided by the associated workflow definition **153**. Once the synthesis engine **127** identifies the common paths among the workflow instances **133**, the actions, as well as inputs, from these paths may be correlated and inserted into a test document **155** associated with the workflow definition **153**. Furthermore, the expected states of the workflow instances **133** that result from each action and input combination may also be correlated and included within the test document **155**. Thereafter, the test document **155** produced by the synthesis engine **127** may be made available in the data store **112** for use and/or further editing.

Referring next to FIG. **2**, shown is a communication diagram **200** that illustrates one example of communication occurring between the test engine **125**, the workflow engine **123**, and an activity **173** during execution of a workflow instance **133** (FIG. **1**) as described above according to an embodiment of the present disclosure. To begin, the test engine **125** requests the current state of a particular workflow instance **133** executed by the workflow engine **123**. The workflow engine **123** requests the workflow definition **153** (FIG. **1**), workflow history **136** (FIG. **1**), and the information embodying the respective workflow instance **133** from the data store **112** (FIG. **1**). Upon receiving the data, the workflow engine **123** determines the next action to be taken for the workflow instance **133**. To this end, the workflow engine **123** having embodied the workflow definition **153**, then examines the workflow history **136** and determines the next action to be taken. Ultimately, the workflow engine **123** generates a directive indicating the next action to be taken with respect to the workflow instance **133**.

In response, the workflow engine **123** may return the present state of the workflow instance **133**. The state information returned may include the workflow history **136** for the workflow instance **133**, whether an action is currently underway, a next action for the workflow instance **133**, whether any input is required for the next action and the format of the input, and/or other data associated with execution of the workflow instance **133** as can be appreciated.

If input is required for the next action, the test engine **125** may provide input specified for the action within the test document **155** (FIG. **1**). In response, the workflow engine **123** may initiate an activity **173** for the next action, as well as potentially provide the input specified by the test document **155** for the action. All needed data to perform the action may be included in the activity request, or the activity request may include a pointer that indicates where such information is stored to be accessed by the respective activity **173**. When sending the activity request, the workflow engine **123** may record an event in the workflow history **136** of the respective workflow instance **133**. The activity **173** then proceeds to schedule, perform, and/or facilitate performance of the respective action associated with the workflow instance **133**. As discussed previously, an action of a workflow may comprise one or more sub-tasks. Each of these sub-tasks or other lineal tasks may themselves require an activity **173**. As a result, one action of a workflow definition **153** may require one or more activities **173** to schedule, perform, and/or facilitate performance of the respective action associated with the workflow instance **133**. Additionally, one or more of the actions and/or sub-tasks of a workflow instance **133** may be performed asynchronously.

Once the activity **173** indicates the next action has been completed, the activity **173** sends a message to the workflow engine **123** that such processing is complete. Thereafter, the workflow engine **123** may provide an update of the state of the workflow instance **133** to the test engine **125**. As described previously, the test engine may compare the state of the workflow instance **133** with the expected state provided by the test document **155**. If the state of the workflow instance **133** matches the expected state of the test document **155**, the test engine **125** may record the results of the test of this action in the workflow log **139** (FIG. **1**), and the workflow instance **133** may proceed to the next action. Alternatively, if the states do not match, the test engine **125** may record the event as a state mismatch and potentially take further responsive action.

Turning now to FIG. **3**, shown is a flowchart that provides one example of the operation of the test engine **125** according to various embodiments. It is understood that the flowchart of FIG. **3** merely provides an example of the many different types of functional arrangements that may be employed to implement the operation of the test engine **125** as described herein. As an alternative, the flowchart of FIG. **3** may be viewed as depicting an example of steps of a method implemented in the computing environment **103** (FIG. **1**) according to one or more embodiments.

This portion of the test engine **125** may be executed based at least upon a workflow definition **153** (FIG. **1**) being selected for testing by the test engine **125**. To begin, in block **303**, the test engine **125** obtains a test document **155** (FIG. **1**) associated with the workflow definition **153**. Then, in block **306**, the test engine **125** may initiate a workflow instance **133** (FIG. **1**), where the workflow instance **133** is an instance of the given workflow definition **153**. In some embodiments, the test engine **125** may be provided with an identifier for a pre-existing workflow instance **133**, thereby bypassing the need to create a new instance.

Next, in block **309**, the workflow engine **123** (FIG. **1**) retrieves any workflow history **136** (FIG. **1**) and workflow definition **153** from the data store **112** (FIG. **1**) for such workflow instance **133**. Once the workflow history **136** and

other information embodying the workflow instance **133** are received by the respective workflow engine **123**, then the workflow engine **123** processes the workflow definition **153** and examines the workflow history **136** in order to determine a next action to be taken for the respective workflow instance **133**.

Then, in block **312**, the test engine **125** determines whether input is required for the next action based upon the state information obtained for the workflow instance **133**. If not input is required, execution of the test engine returns to block **309**. Alternatively, if input is required, execution of the test engine **125** proceeds to block **315**. At block **315**, the test engine **125** may communicate the input to the workflow engine **123**. If the test document **155** does not specify an input for a given action, the test engine **125** may obtain the input from a user through a user-interface and/or from another input source as can be appreciated.

Continuing, at block **318**, the test engine **125** may obtain the state of the workflow instance **133** resulting from performance of the action. Moving on, at block **321**, the test engine **125** may compare the data associated with the state of the workflow instance **133** after completing the activity **173** (FIG. **1**) with the expected state of the workflow instance specified by the test document **155**. Such a comparison may permit testing of not only the operation of the workflow instance **133**, but potentially the operation of one or more applications **163** (FIG. **1**) carrying out the action.

Next, at block **324**, the test engine **125** determines whether the state of the workflow instance **133**, including the data returned by the application **163** (FIG. **1**), matches the expected state of the test document **155**. If the states match, execution of the test engine **125** returns to block **312** to determine if the present state of the workflow instance requires input. Alternatively, if the states do not match, in block **327**, the test engine **125** may record the event in the workflow log **139** (FIG. **1**) as a state mismatch and initiate a responsive action to the mismatch as described previously. Thereafter, this portion of the execution of the test engine **125** may end as shown.

With reference to FIG. **4**, shown is a flowchart that provides one example of the operation of the synthesis engine **127** according to various embodiments. It is understood that the flowchart of FIG. **3** merely provides an example of the many different types of functional arrangements that may be employed to implement the operation of the synthesis engine **127** as described herein. As an alternative, the flowchart of FIG. **4** may be viewed as depicting an example of steps of a method implemented in the computing environment **103** (FIG. **1**) according to one or more embodiments.

This portion of the synthesis engine **127** may be executed based at least upon a request from an operator to examine workflow histories **136** (FIG. **1**) in order to produce one or more test documents **155** (FIG. **1**). To begin, in block **403**, the synthesis engine **127** may obtain workflow histories **136** associated with one or more of prior executions of various workflow instances **133***a*-N (FIG. **1**). Next, in block **406**, the synthesis engine **127** may identify the workflow definitions **153***a*-N (FIG. **1**) represented by prior executions of workflow instances **133***a*-N.

Then, in block **409**, the synthesis engine **127** may correlate the various workflow instances **133** associated with a given workflow definition **153** in order to identify common paths of execution taken from among the various potential paths of the workflow definition **153**. Continuing, in block **412**, the synthesis engine **127** may generate one or more test scenarios based upon the various actions, inputs, and resulting states taken along these common paths. Next, in block **415**, the synthesis engine **127** may insert the test scenarios in the test document **155** associated with the workflow definition **153**. Thereafter, in block **418**, the synthesis engine **127** may determine if further workflow definitions **153***a*-N were represented in the workflow histories **136** for which the workflow instances **133***a*-N have not been examined. If more workflow definitions **153***a*-N remain, execution of the synthesis engine **127** returns to box **409**. Alternatively, if no further workflow definitions **153***a*-N exist for which the associated workflow instances **133***a*-N have not been examined, this portion of the synthesis engine **127** ends as shown.

Turning now to FIG. **5**, shown is a schematic block diagram of the computing environment **103** according to an embodiment of the present disclosure. The computing environment **103** may comprise, for example, one or more computing devices **500**. A computing device **500** includes at least one processor circuit, for example, having a processor **503** and a memory **506**, both of which are coupled to a local interface **509**. The local interface **509** may comprise, for example, a data bus with an accompanying address/control bus or other bus structure as can be appreciated.

Stored in the memory **506** are both data and several components that are executable by the processor **503**. In particular, stored in the memory **506** and executable by the processor **503** are the workflow engine **123**, the test engine **125**, the synthesis engine **127**, and potentially other applications. Also stored in the memory **506** may be a data store **112** and other data. In addition, an operating system may be stored in the memory **506** and executable by the processor **503**.

It is understood that there may be other applications that are stored in the memory **506** and are executable by the processors **503** as can be appreciated. Where any component discussed herein is implemented in the form of software, any one of a number of programming languages may be employed such as, for example, C, C++, C#, Objective C, Java, Javascript, Perl, PHP, Visual Basic, Python, Ruby, Delphi, Flash, or other programming languages.

A number of software components are stored in the memory **506** and are executable by the processor **503**. In this respect, the term "executable" means a program file that is in a form that can ultimately be run by the processor **503**. Examples of executable programs may be, for example, a compiled program that can be translated into machine code in a format that can be loaded into a random access portion of the memory **506** and run by the processor **503**, source code that may be expressed in proper format such as object code that is capable of being loaded into a random access portion of the memory **506** and executed by the processor **503**, or source code that may be interpreted by another executable program to generate instructions in a random access portion of the memory **506** to be executed by the processor **503**, etc. An executable program may be stored in any portion or component of the memory **506** including, for example, random access memory (RAM), read-only memory (ROM), hard drive, solid-state drive, USB flash drive, memory card, optical disc such as compact disc (CD) or digital versatile disc (DVD), floppy disk, magnetic tape, or other memory components.

The memory **506** is defined herein as including both volatile and nonvolatile memory and data storage components. Volatile components are those that do not retain data values upon loss of power. Nonvolatile components are those that retain data upon a loss of power. Thus, the memory **506** may comprise, for example, random access memory (RAM), read-only memory (ROM), hard disk drives, solid-state drives, USB flash drives, memory cards accessed via a memory card reader, floppy disks accessed via an associated floppy disk

drive, optical discs accessed via an optical disc drive, magnetic tapes accessed via an appropriate tape drive, and/or other memory components, or a combination of any two or more of these memory components. In addition, the RAM may comprise, for example, static random access memory (SRAM), dynamic random access memory (DRAM), or magnetic random access memory (MRAM) and other such devices. The ROM may comprise, for example, a programmable read-only memory (PROM), an erasable programmable read-only memory (EPROM), an electrically erasable programmable read-only memory (EEPROM), or other like memory device.

Also, the processor **503** may represent multiple processors **503** and the memory **506** may represent multiple memories **506** that operate in parallel processing circuits, respectively. In such a case, the local interface **509** may be an appropriate network **109** (FIG. **1**) that facilitates communication between any two of the multiple processors **503**, between any processor **503** and any of the memories **506**, or between any two of the memories **506**, etc. The local interface **509** may comprise additional systems designed to coordinate this communication, including, for example, performing load balancing. The processor **503** may be of electrical or of some other available construction.

Although the workflow engine **123**, the test engine **125**, the synthesis engine **127**, and other various systems described herein may be embodied in software or code executed by general purpose hardware as discussed above, as an alternative the same may also be embodied in dedicated hardware or a combination of software/general purpose hardware and dedicated hardware. If embodied in dedicated hardware, each can be implemented as a circuit or state machine that employs any one of or a combination of a number of technologies. These technologies may include, but are not limited to, discrete logic circuits having logic gates for implementing various logic functions upon an application of one or more data signals, application specific integrated circuits having appropriate logic gates, or other components, etc. Such technologies are generally well known by those skilled in the art and, consequently, are not described in detail herein.

The flowcharts of FIGS. **3** and **4** show the functionality and operation of an implementation of portions of the test engine **125** and synthesis engine **127**, respectively. If embodied in software, each block may represent a module, segment, or portion of code that comprises program instructions to implement the specified logical function(s). The program instructions may be embodied in the form of source code that comprises human-readable statements written in a programming language or machine code that comprises numerical instructions recognizable by a suitable execution system such as a processor **503** in a computer system or other system. The machine code may be converted from the source code, etc. If embodied in hardware, each block may represent a circuit or a number of interconnected circuits to implement the specified logical function(s).

Although the flowcharts of FIGS. **3** and **4** show a specific order of execution, it is understood that the order of execution may differ from that which is depicted. For example, the order of execution of two or more blocks may be scrambled relative to the order shown. Also, two or more blocks shown in succession in FIGS. **3** and **4** may be executed concurrently or with partial concurrence. Further, in some embodiments, one or more of the blocks shown in FIGS. **3** and **4** may be skipped or omitted. In addition, any number of counters, state variables, warning semaphores, or messages might be added to the logical flow described herein, for purposes of enhanced utility, accounting, performance measurement, or providing troubleshooting aids, etc. It is understood that all such variations are within the scope of the present disclosure.

Also, any logic or application described herein, including the workflow engine **123**, the test engine **125**, and the synthesis engine **127**, that comprises software or code can be embodied in any non-transitory computer-readable medium for use by or in connection with an instruction execution system such as, for example, a processor **503** in a computer system or other system. In this sense, the logic may comprise, for example, statements including instructions and declarations that can be fetched from the computer-readable medium and executed by the instruction execution system. In the context of the present disclosure, a "computer-readable medium" can be any medium that can contain, store, or maintain the logic or application described herein for use by or in connection with the instruction execution system. The computer-readable medium can comprise any one of many physical media such as, for example, magnetic, optical, or semiconductor media. More specific examples of a suitable computer-readable medium would include, but are not limited to, magnetic tapes, magnetic floppy diskettes, magnetic hard drives, memory cards, solid-state drives, USB flash drives, or optical discs. Also, the computer-readable medium may be a random access memory (RAM) including, for example, static random access memory (SRAM) and dynamic random access memory (DRAM), or magnetic random access memory (MRAM). In addition, the computer-readable medium may be a read-only memory (ROM), a programmable read-only memory (PROM), an erasable programmable read-only memory (EPROM), an electrically erasable programmable read-only memory (EEPROM), or other type of memory device.

It should be emphasized that the above-described embodiments of the present disclosure are merely possible examples of implementations set forth for a clear understanding of the principles of the disclosure. Many variations and modifications may be made to the above-described embodiment(s) without departing substantially from the spirit and principles of the disclosure. All such modifications and variations are intended to be included herein within the scope of this disclosure and protected by the following claims.

Therefore, the following is claimed:

1. A non-transitory computer-readable medium embodying a program executable in a computing device, the program comprising:

code that acquires a test document associated with a workflow definition in response to receiving the workflow definition comprising a plurality of possible paths of execution, individual ones of the plurality of possible paths of execution comprising a sequence of a plurality of actions, the test document comprising a programmatic input source configured to provide an input for at least one of the plurality of actions of the workflow definition and an expected state for the workflow definition based at least on the input;

code that places a workflow instance in a queue accessible to a workflow engine in the computing device, the workflow instance being an instance of the workflow definition;

code that provides the input from the programmatic input source for the at least one of the plurality of actions of the workflow instance to the workflow engine managing the workflow instance, the at least one of the plurality of actions determined based at least in part upon a present state of the workflow instance and being performed by a remote application, the remote application interfacing with the workflow engine and returning a result, the

input being determined upon execution of the at least one of the plurality of actions of the workflow instance;

code that generates a comparison of a next state of the workflow instance to the expected state of the test document in response to receiving the next state of the workflow instance, the next state being based at least in part upon the present state, the at least one of the plurality of actions, the input, and the result, wherein the comparison comprises the result of the remote application; and

code that restarts the workflow instance at a beginning of the workflow instance based at least in part on a difference in the comparison.

2. The non-transitory computer-readable medium of claim **1**, further comprising code that provides an initial state of the workflow instance, the test document further comprising the initial state.

3. The non-transitory computer-readable medium of claim **1**, further comprising code that generates a plurality of common actions for use with future workflow instances, wherein the plurality of common actions are inserted within the test document and the plurality of common actions are based at least in part upon a transaction log from a plurality of prior executions of a plurality of prior workflow instances, the plurality of prior workflow instances being associated with the workflow definition.

4. A non-transitory computer-readable medium embodying a program executable in a computing device, the program comprising:

code that acquires a test document associated with a workflow definition comprising a plurality of possible paths of execution, individual ones of the plurality of possible paths of execution comprising a sequence of a plurality of actions, wherein the test document comprises a programmatic input source configured to provide an input for at least one of the plurality of actions of the workflow definition and an expected state for the workflow definition based at least in part on the input;

code that, in response to receiving the workflow definition, places a workflow instance in a queue accessible to a workflow engine in the computing device, the workflow instance being an instance of the workflow definition;

code that provides the input from the programmatic input source for the at least one of the plurality of actions of the workflow instance to the workflow engine managing the workflow instance, the at least one of the plurality of actions determined based at least in part upon a present state of the workflow instance and being performed by a remote application, the remote application interfacing with the workflow engine and returning a result, the input being determined upon execution of the at least one of the plurality of actions of the workflow instance;

code that, in response to receiving a next state of the workflow instance, generates a comparison of the next state of the workflow instance to the expected state of the test document, wherein the next state is based at least in part upon the present state, the at least one of the plurality of actions, the input, and the result, and wherein the comparison comprises the result of the remote application; and

code that restarts the workflow instance at a beginning of the workflow instance based at least in part on a difference in the comparison.

5. The non-transitory computer-readable medium of claim **4**, wherein the at least one of the plurality of actions comprises a plurality of sub-tasks and the input comprises at least one sub-input for the plurality of sub-tasks.

6. The non-transitory computer-readable medium of claim **5**, wherein the at least one of the plurality of actions is not complete until the plurality of sub-tasks are completed.

7. A system, comprising:

at least one computing device; and

a test engine executable in the at least one computing device, the test engine comprising:

logic that delivers an input for an action of a workflow instance, a test document executed by the test engine determining the input from a programmatic input source based at least in part upon the action, and a workflow engine executing the workflow instance determining the action based at least in part upon a present state of the workflow instance, the input being determined upon execution of the action of the workflow instance;

logic that, in response to receiving a next state of the workflow instance, compares the next state of the workflow instance to the test document, wherein the next state is determined by the workflow engine based at least in part upon the present state, the action, and the input, and wherein the test document comprises an expected state of the workflow instance; and

logic that restarts the workflow instance at a beginning of the workflow instance based at least in part on a result of a comparison of the next state of the workflow instance to the test document.

8. The system of claim **7**, wherein the workflow instance is an instance of a workflow definition comprising a plurality of possible paths of execution, and the test document is associated with the workflow definition.

9. The system of claim **8**, further comprising logic that generates an additional test scenario that is inserted into the test document based at least in part upon a log of a plurality of prior instances of the workflow definition, the plurality of prior instances representing a subset of the plurality of possible paths of execution of the workflow definition.

10. The system of claim **9**, wherein the log indicates that at least one of the plurality of prior instances of the workflow definition produced an error.

11. The system of claim **8**, wherein the test engine further comprises logic that generates an event based at least in part upon a difference between the next state of the workflow instance and the expected state of the test document.

12. The system of claim **11**, further comprising logic that instructs the workflow engine to repeat the action using the present state and the input, wherein the workflow engine is scheduled to perform the action associated with the present state for the next state of the workflow instance.

13. The system of claim **7**, wherein the action is performed by a remote application, the remote application interfacing with the workflow instance and returning a result.

14. The system of claim **7**, wherein the action comprises a plurality of sub-tasks and the input comprises at least one sub-input for the plurality of sub-tasks.

15. A method, comprising:

receiving, via at least one of one or more computing devices, a test document associated with a workflow definition, the test document comprising a programmatic input source configured to provide an input for an action of the workflow definition and an expected state for the workflow definition based at least in part on the input;

delivering, via at least one of the one or more computing devices, the input from the programmatic input source for the action of a workflow instance, the workflow instance being a first instance of the workflow definition

executed by a workflow engine, and the action determined based at least in part upon a present state of the workflow instance, the input being determined upon execution of the action of the workflow instance;

receiving, via at least one of the one or more computing devices, a next state of the workflow instance, the next state being determined by the workflow engine based at least in part upon the present state, the action, and the input;

comparing, via at least one of the one or more computing devices, the next state of the workflow instance to the expected state specified by the test document; and

restarting, via at least one of the one or more computing devices, the workflow instance at a beginning of the workflow instance in response to detecting a discrepancy between the next state of the workflow instance and the expected state specified by the test document in response to comparing the next state of the workflow instance to the expected state specified by the test document.

16. The method of claim **15**, further comprising generating, via at least one of the one or more computing devices, an alarm based at least in part upon a difference between the next state of the workflow instance and the expected state of the test document.

17. The method of claim **15**, wherein a portion of the test document is generated based at least in part upon a log from a prior execution of a prior workflow instance, the prior workflow instance being a second instance of the workflow definition.

18. The method of claim **15**, wherein the action comprises at least one sub-task and the input comprises a sub-input for the at least one sub-task.

19. The method of claim **18**, wherein the action is not complete until the at least one sub-task is completed.

20. The method of claim **15**, wherein the test document is a JavaScript object notation (JSON) document.

21. The method of claim **15**, further comprising initiating, via at least one of the one or more computing devices, the workflow instance based at least in part upon the workflow definition specified by the test document.

22. The method of claim **15**, wherein the action is performed by a remote application, the remote application interfacing with the workflow instance and returning a result.

23. The method of claim **22**, wherein comparing, via at least one of the one or more computing devices, the next state of the workflow instance to the expected state of the test document further comprises performing a comparison of the result from the remote application to the expected state of the test document, the expected state of the test document comprising an expected result from the remote application.

24. The non-transitory computer-readable medium of claim **3**, further comprising:

code that generates an additional test scenario based at least in part upon the plurality of common actions, a plurality of corresponding inputs associated with the plurality of common actions, and a corresponding plurality of results associated with the plurality of common actions; and

code that inserts the additional test scenario within the test document.

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